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## ON THE CORRELATION BETWEEN GROWTH AND FOOD SUPPLY IN STARFISH.

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IN the higher vertebrates there is a pretty constant relation between the age of an individual and its size, at least up to the time when the full stature is reached. This relation is expressed in carefully constructed curves of growth, and it may be inferred from common observation. The healthy individual must be able, during its early life, not only to hold its own in respect to size, but also to grow ; the time between meals must be comparatively short, and the nourishment assimilated must be more than sufficient merely to replenish waste tissue. Minot has shown for guinea pigs that even "any irregularity in the growth of an individual tends to be followed by an opposite compensating irregularity." "If an individual grows for a period exceedingly fast, there immediately follows a period of slower growth ; and, *vice versa*, those that remain behind for a time, if they remain in good health, make up the loss (at least in great part if not always completely) soon after." "Each individual appears to be striving to reach a particular size" — a particular size, we might add, not only for the adult age but for any particular previous age.

The normal rate of growth of marine invertebrates seems not to have received much attention, and were one to inquire among longshoremen or seaside naturalists how old an eight-inch lobster is, or how long it takes a starfish to grow to a certain size or to become sexually mature, he would meet with an interesting variety of opinions and receive little satisfactory information.

Several years ago Alexander Agassiz made an estimate of the rate of growth in starfishes, which was based upon the supposition that a close relation does obtain between size and age in these animals as well as in vertebrates. The method which he

employed was previously used by the elder Agassiz for ascertaining the age of many marine animals (*Proc. Essex Inst.*, 1863), and is explained in the following quotation from the monograph on North American starfishes :

"The young starfishes figured on this plate (Pl. VIII) were all found attached to roots of *Laminaria* thrown up on the beaches in the neighborhood after a storm; and from their different stages of growth, as compared with the oldest starfish raised from a brachiolarian (Pl. VI, Fig. 11), specimens of which were also found upon these roots, it is probable that the sizes here figured are one (Fig. 1), two (Fig. 8), and three (Fig. 10) years old. A considerable number of specimens were picked up in this way, and they could all be arranged into very distinct groups, representing the starfishes of the present and two previous seasons. There seemed to be no gradation from one group to another, such as we have among the young sea urchins, which, in consequence of their manner of breeding during the whole year, form series the relations of which it is impossible to determine. In this connection I would say that, by arranging the starfishes found upon our rocks into series according to their size, we are able to obtain a rough estimate of the number of years required by them to attain their full development; this I presume to be somewhere about fourteen years. They begin to spawn before that time, as specimens have been successfully fecundated which evidently were not more than six or seven years old."

During the summer of 1898 the writer had an excellent opportunity to study the rate of growth of the starfish (*Asterias forbesii*) at a floating laboratory moored in one of the estuaries of Narragansett Bay. The breeding season was short and definite, and the larvæ began to "set" the last of June.

On June 29, innumerable young starfish, about as large as the head of a pin, were discovered clinging to the eel-grass and to the rockweed and other algæ, where a few days before none could be found. A handful of the fluffy seaweed, *Heteromorpha*, bespangled with minute stars, was placed in a floating car, whose sides were encrusted with a young growth of barnacles, fresh fronds of green algæ, and delicate branch-

ing stalks of hydroids. That the little starfish found here a natural and congenial environment was evident from their healthy appearance, their quick response, and their rapid growth.

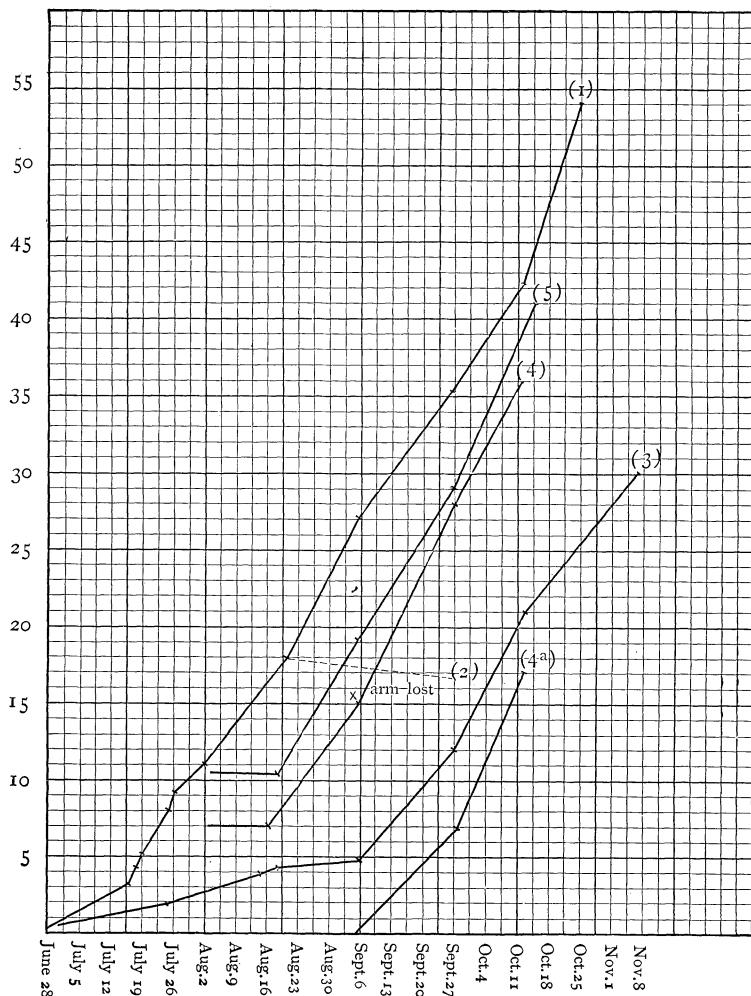


FIG. 1.

They were kept under observation until November and fed on barnacles, small clams, and mussels. As they were examined from time to time, two features of their growth were especially noteworthy, *viz.*, its rapidity and the difference in rate in

different individuals. On June 29 none of the stars measured more than 1 mm.;<sup>1</sup> on July 18 one of the larger specimens measured 5 mm.; July 26, 9 mm.; August 18, 18 mm.; September 26, 35 mm.; October 25, 54 mm. (over 2 inches). Curve 1, Fig. 1, is a graphic representation of the growth of these stars and is constructed from measurements of the largest specimens which could be found in the car at each observation. At any time after the first few weeks some of the specimens were three times as large as others, and between these all intermediate stages could be found. On August 18, for instance, eight specimens, arranged according to their sizes, measured  $7\frac{1}{2}$ ,  $8\frac{1}{2}$ ,  $10\frac{1}{2}$ , 12, 13,  $14\frac{1}{2}$ , 16, and 18 mm. A similar series — or a more perfect one — might at any time be arranged from specimens taken along the shores.

From the fact that in starfish of the same age such great differences in size exist, with all gradations between the extremes, it is evident that there is danger in applying to them Agassiz's method of ascertaining age. Indeed, the specimens which were calculated by him to be three years old were not one-fifth as large — linear measurement — as those known by actual observation to be only three months old.

Coming now to the consideration of the conditions which determine the *difference* in the rate of growth in these animals, we may exclude certain factors at once; for example, the influence of light, temperature and density of the water, and size of containing vessel, inasmuch as these conditions are practically the same for all the individuals under observation.

It appears from some other experiments, however, that difference in the amount of food is the principal, if not the only, factor. The starfish differs from the higher animals in this important respect; it can eat and *assimilate* many times as much food as is necessary merely to maintain a healthy condition. When food is accessible, the starfish eats voraciously and grows with great rapidity; but, on the other hand, it will live for months almost without food and apparently remain healthy, though it does not grow. As one watches a large

<sup>1</sup> All the measurements given below as "length" are from the mouth to tip of arm.

number of stars of the same age and size, transferred to a new car, he will not fail to notice that some of them happen upon a favorable food supply before the others, and in consequence grow at first much faster than the rest. Then, not only do these larger specimens have the better chance of getting food, but, if the animals usually preyed upon become scarce, the larger starfish do not hesitate to devour the smaller ones. It was noticed repeatedly that the variation in the rate of growth was much greater among the starfish whose food supply was limited than among those abundantly provided for. The immediate effect upon the rate of growth of the supplying and the withholding of food is demonstrated in the following experiments.

One of the starfishes in the car which had grown most rapidly up to August 18, when it measured 18 mm. (see curve 1), was kept until September 26 with very little to eat. During these five weeks there was no growth in this specimen (curve 2), but rather a slight decrease, although the largest specimen left in the car had doubled its length.

Another small starfish (curve 3), which was caught in the tow net as a brachiolarian and "set" in the aquarium on June 28, was kept on a very small allowance of food until July 23, when it measured 2 mm. It was then fed occasionally on small barnacles, and on September 6 measured 5 mm. After this it was given an abundance of food, with the following result: September 26, 12 mm.; October 12, 21 mm.; November 5, 30 mm.

Several other starfish which were caught in the tow and set in an aquarium at the same time with the last were kept on a small allowance until September 6, and were then apparently in good health, although they had grown but little. Fig. 2 *A* represents one of these at the age of about five weeks, and Fig. 2 *B* represents a well-nourished specimen of the same age, taken from the car.

Two specimens (curves 4, 5) of medium size, 7 mm. and 10½ mm., respectively, were transferred, on August 3, from the original car, where they had been reared on barnacles, to an adjacent car. They were supplied with a bunch of

small mussels, which, however, the starfish could not or would not open, and on August 16, after a period of thirteen days, they had not grown at all. From this time they were provided with an abundance of their usual food — barnacles — and grew with great rapidity, as is indicated in the curves. On November 12 they measured, respectively, 36 and 41 mm.

Incidentally curve 4 shows another interesting point, namely, that the loss of an arm does not cause a diminution in the rate of growth. On September 5 an arm was accidentally torn off, yet the rate of growth of the rest of the body was as rapid as

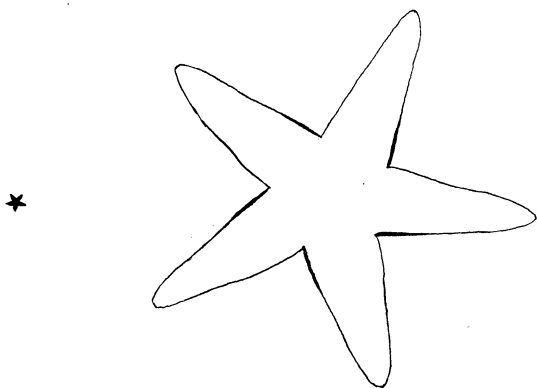


FIG. 2 A.

FIG. 2 B.

These figures represent two starfishes of the same age ( $5\frac{1}{2}$  weeks).

before, and as rapid as that of the other starfish (curve 5). The rate of growth in the regenerating member is indicated in curve 4 *a*.

The age at which the starfish becomes sexually mature also depends upon the rate of growth; in other words, a starfish must attain a certain size before it may become sexually mature. During May, the month preceding the breeding season, nearly all the starfishes measuring over 50 mm. (2 inches) are full of ripe sex products, and occasionally ripe specimens are taken which measure only 32 mm. Larvæ have been obtained by artificial fertilization from parents measuring 38 mm. Now many of the starfishes raised in the car were considerably more than 38 mm. in length on October 25, three months after

setting, and their sex glands were quite as well developed as they were in the average stars of any size at that season of the year. Allowing the very moderate estimate of 15 mm. for the growth of such individuals during the next six months, in May they would be more than 50 mm. in length, and such specimens are, with rare exceptions, sexually mature. We are warranted in inferring, therefore, that well-nourished starfishes arrive at sexual maturity and breed before they are a year old.

On the other hand, it is evident that many starfishes do not reach sexual maturity in one year, since small, immature specimens, between 10 and 20 mm. in length, are not uncommon just before the breeding season begins.

Desultory observations on other marine invertebrates, *e.g.*, the clam, oyster, and lobster, indicate that the conditions of their growth are essentially similar to those of the starfish, and to this extent substantiate the conclusion that between the higher and lower animals there are fundamental differences in the phenomena of growth.

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